Simulation of the binaural environmental transfer function for gerbils using a boundary element method

[illegible][a]

[illegible]

[illegible]
[illegible] Boston, MA [illegible]

(September 21, 2007)

Running title:

---

[a] Electronic mail: sgrace@bu.edu

ABSTRACT

The auditory system relies on spectral notches in the binaural environmental transfer function (BETF) as cues for localization of sources in the median plane. Experiments have shown that the BETF for gerbils in free space, regularly termed the head related transfer function (HRTF), contains a single notch in the ultrasonic range, while the BETF for a gerbil standing on a solid surface contains several notches at much lower frequency due to comb-filtering effects. In this research, the BETF for a model gerbil geometry is computed using a boundary element method (BEM). A parallel implementation of the BEM that includes the CHIEF regularization scheme is applied. The gerbil's BETFs for various source elevations and distances in the free-field and in the presence of a solid surface are computed. Comparisons with gerbil HRTF measurements show good agreement. The reflection due to the solid surface is shown to provide an acoustic cue for source elevation as well as source distance. It is demonstrated that the full variation of the BETF with source location can only be captured through a simulation that can account for both the solid surface and the gerbil and their combined influence on the sound field.

PACS numbers: 43:66Qp, 43:64Bt, 43:64Ha.

1. INTRODUCTION

the HRTF of humans is reported in (Blauert, 1993), the monkey's HRTF is reported in (Spezio *et al.*, 2000), gerbil HRTF's can be found in Maki *et al.* (2003a), and several researchers have measured the HRTF for cats (Musicant *et al.*, 1990; Rice *et al.*, 1992; Xu and Middlebrooks, 1980; Young *et al.*, 1996). Some BETF measurements have been made in an attempt to exo3409557u 0n T78093 0410482F ronment are qualitatively compared to experimental results and are used to explore more shown in this paper. Finally, the results are discussed.

2. BAC

surface discretization that has at least 10 points per wave length, the surface panels

dB, hence

$$\mathbf{BETF} = 20\,\mathbf{Log}\left(\frac{\hat{\mathbf{p}}}{\mathbf{p}^I}\right)\mathbf{;} \tag{1}$$

where $\hat{\mathbf{p}}$ is the amplitude of the total pressure and $\mathbf{p}^I$ the incident pressu

TABLE I. Model geometry specs.

Ear		
Length	0.013 **m**	0.013 **m**
Width	0.004 **m**	0.004 **m**
Depth	0.006 **m**	0.004 **m**
Inclination	20°	20°
Distance btw Ears	0.02 **m**	0.02 **m**
Head		
Length	0.033 **m**	
Radius (X dir)	0.012 **m**	
Radius (Z dir)	0.010 **m**	
Torso		
Height	0.088 **m**	
Radius (X dir)	0.025 **m**	
Radius (Y dir)	0.020 **m**	
Inclination	60°	
Floor		
Distance from Ear	0.095 **m**	
Width	0.4 **m** × 0.4 **m**	
Thickness	0.001 **m**	

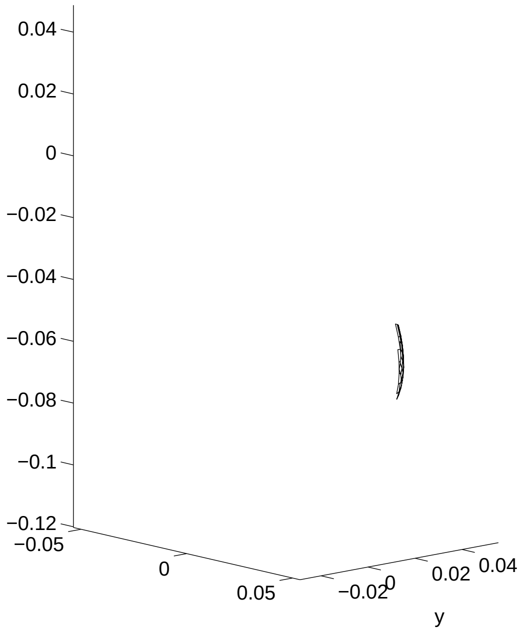

0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
−0.12
−0.05
0
0.05
−0.02
0
0.02
0.04
y

TABLE II. Geometry Discretization. Number of Panels.

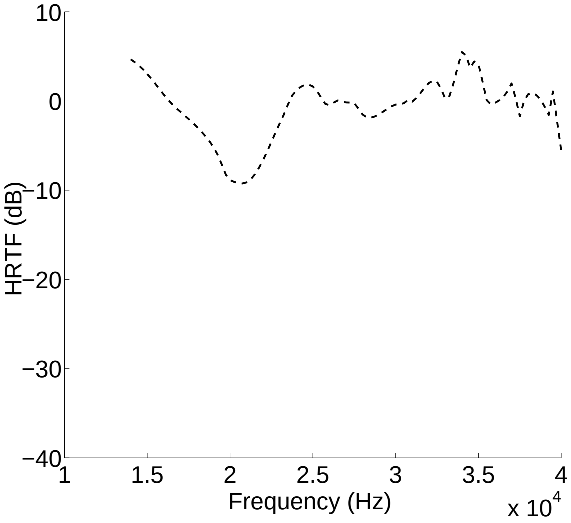
	Low Frequency 0:5 – 14 **kHz**	High Frequency 14 – 40 **kHz**
First Ear	2390	5494
Head	4860	11016
Torso	6400	10000
Floor (top)	14400	N/A

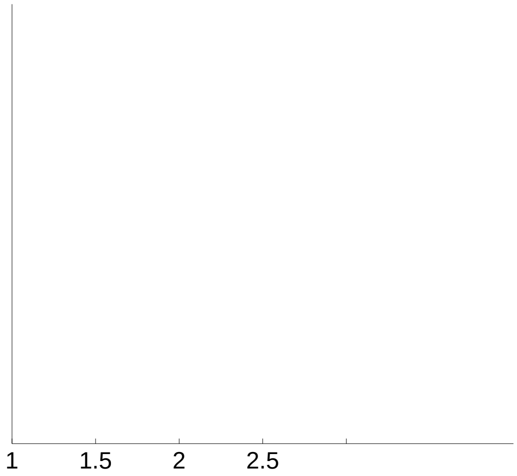
grid and same source location take only 15 minutes. Thus a complete run for a single source location using 120 frequencies takes approximately 30 hours.

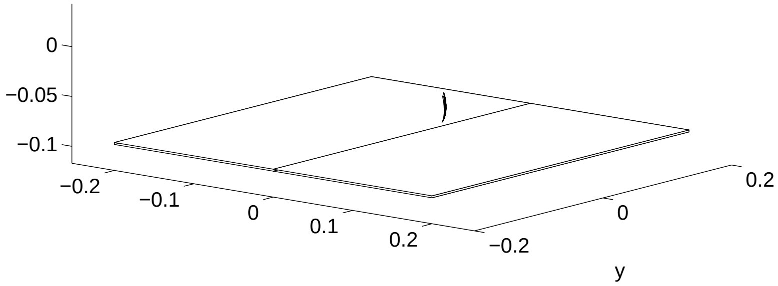
The following questions were addressed:

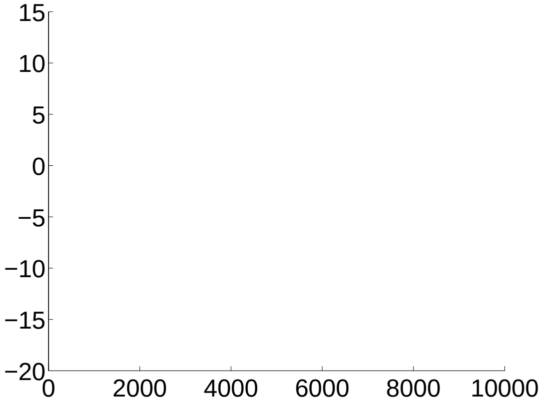
- How sensitive is the computed BETF to the choice of measurement location at the base of the pinna?
- How sensitive is the computed BETF to ear geometry, and is this consistent across experiments?
- How do the computed results compare with the experimental data?
- Can the effect of environmental cues on the BETF be captured by a BEM simulation? If so, what can we learn from the simulations regarding the importance of such cues on perception?
- Can physical insights be gained by choosing different definitions of the incident field when computing the BETF?

at the base of the pinna was av


10
0
−10
−20
−30
−40
HRTF (dB)
1
1.5
2
2.5
3
3.5
4
Frequency (Hz)
x 10^4

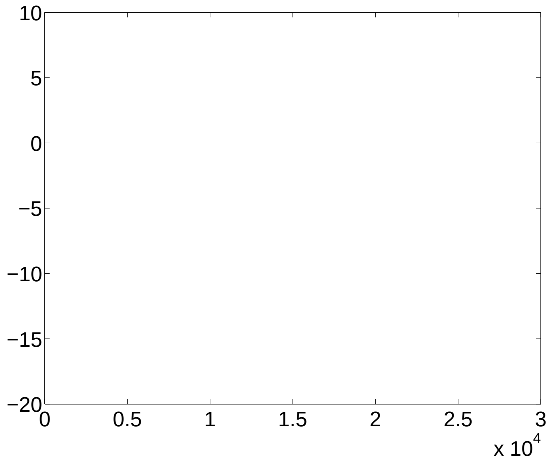

1
1.5
2
2.5


0
−0.05
−0.1
−0.2
−0.1
0
0.1
0.2
−0.2
0
0.2
y


15
10
5
0
−5
−10
−15
−20
0
2000
4000
6000
8000
10000

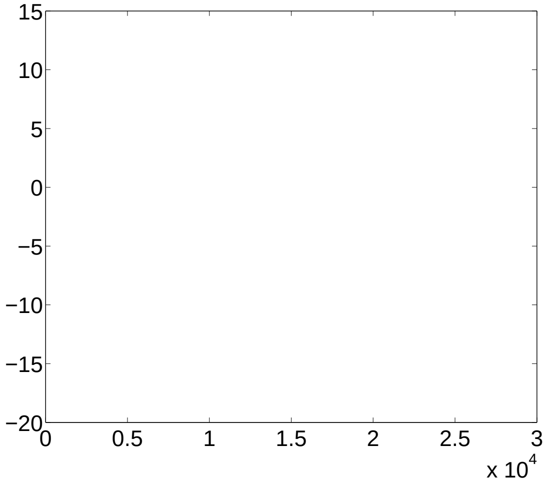
frequency of 1700 **Hz**. Figure 9 shows that the thin box and image methods differ the most at multiples of 1700 **Hz**, emphasizing the importance of the box edge scattering in the BETF. The distance of the gerbil ear from the floor is 0.095 **m**, which relates to a frequency of 3580 **Hz**. At frequencies below 8 **kHz**, the difference between the computation that includes the gerbil and the computation for just the floor scattering is greatest at multiples of this frequency. Past a frequency of roughly 8 **kHz**, when other geometric details such as the head size become much more important, all of the methods diverge.

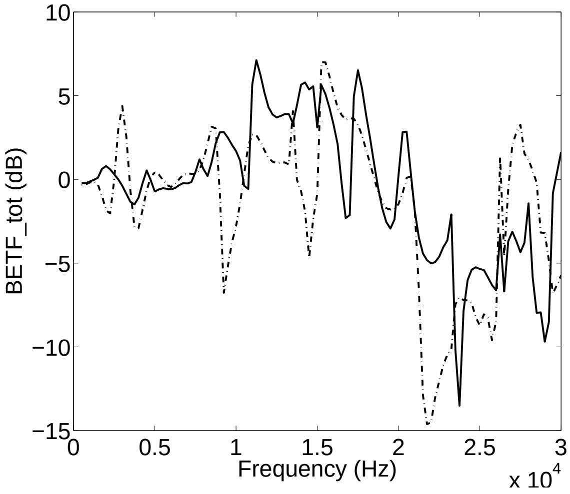
Originally, the thin box model was developed to simulate the finite extent floor that was used in experiment. However, it is computationally less intensive to study the impact of source distance for example if one uses the infinite floor model (image method) because of the increased grid size that accompanies discretizing a thin box with large extent. Because the main differences between the thin box results and the infinite floor results arise at frequencies associated with the length scale related to the finite floor, and the salient features of the comb-filtering

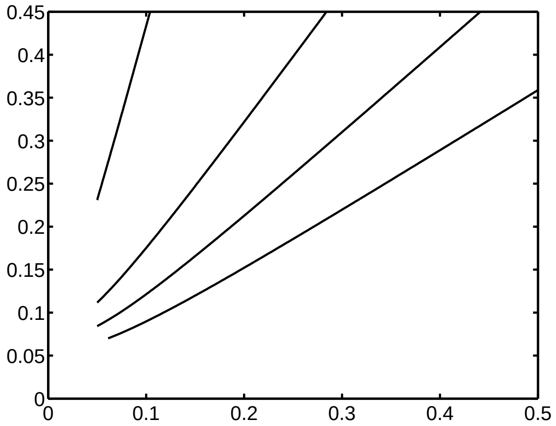

10
5
0
−5
−10
−15
−20
0
0.5
1
1.5
2
2.5
3
x 10^4

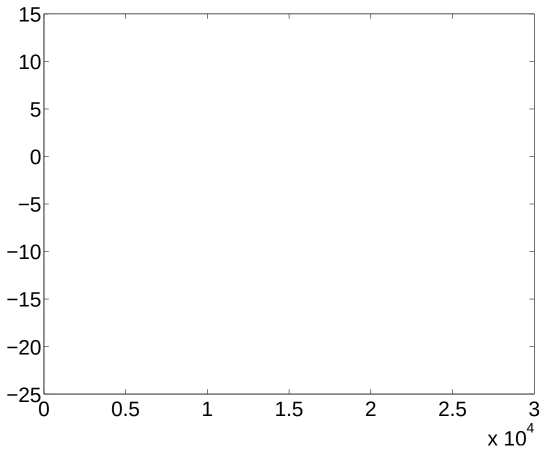
reported by Maki *et al.* (2003b) because they are dominated by the environmental input. As pointed out by Maki *et al.*, these environmentally produced notches justify the neurological behavior of the gerbil DCN that shows excitatory responses to best frequency tones as low as 1 **kHz**.

If one is interested in the importance of the interaction between the environmental cues and the gerbil geometry, it is better to normalize the total pressure at the base of the pinna by the total incident pressure (i.e. the pressure field due to the environment at the pinna location when only the gerbil is absent). When this normalization factor is used, the comb filtering is factored out. What appears are the variations due to various geometrical length scales related to the gerb normalization. The results highlight the fact that the reflected energy from the floor can provide source elevation cues.




10
5
0
−5
−10
−15
BETF_tot (dB)
0
0.5
1
1.5
2
2.5
3
Frequency (Hz)
x 10^4


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5


15
10
5
0
−5
−10
−15
−20
−25
0
0.5
1
1.5
2
2.5
3
x 10^4

cided with the location of the maxima in the velocity potential when not regularized. However, a more robust regularization method is recommended for future use because of the poor performance of the CHIEF method at very high frequency.

A simplified gerbil geometry was created based on anatomical data from gerbils used in empirical experiments and the gerbil was treated as a rigid scatterer. These empirical results provide the validation data for the current study. The is on a solid surface, e.g. < 10kHz for the second ear model, are highly dependent upon the interference pattern set up by the reflections from the surface. However, the augmentation of the comb filtering due to the gerbil geometry is present at the lower frequencies. This contribution of the gerbil's anatomy to the BETF for the case of a gerbil standing on a solid surface is best highlighted using the [illegible] incident pressure as the normalization factor in the BETF.

The results reported here thus indicate that reflected energy can provide information about source elevation as well as source distance. Moreover, the environmental cues are influenced by the listener geometry and its interactions with the environment and thus cannot simply be superimposed on an HRTF to produce the BETF.

The BEM has been shown to be a powerful tool for predicting the BETF of gerbils in real environments. This tool can now be used to study the effect of environmental inhomogeneities, environmental and animal fur acoustic absorption, and predator sound cues.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge Prof. Maki's willingness to share his data with us as well as a copy of his poster from the Association for Research in Otolaryngology conference. We also thank Professor Umberto Iemma of the University of Rome III for sharing his basic boundary element code with us. Finally, we extend our thanks to Profs. Steve Colburn, and Paul Barbone for their thoughtful discussions throughout this project. This work was partially supported by the Hearing Research Center at Boston University.

References

L. S. Blackford, J. Choi, A. Cleary, E. D'Azevedo, J. Demmel, I. Dhillon, J. Dongarra, S. Hammarling, G. Henry, A. Petitet, K. Stanley, D. Walker, and R. C. Whaley, *ScaLAPACK Users' Guide*, Philadelphia (1997).

J. Blauert, *The Psychophysics of Human Sound Localization* (Cambridge: MIT Press) (1993).

J. Fels, P. Buthmann, and M. Vorlander, Head-Related Transfre Functions of Children. Acta Acustica United with Acustica **90** (2004) 918–927.

W. M. Hartmann, B. Rakerd, and A. Koller, Binaural coherence in rooms. Acustica united with Acta Acustica **91**(3) (2005) 451–62.

U. Iemma, BEM simulation of woodwind musical instruments. in *Seventh International Congress on Sound and Vibration* (Garmisch-Partenkirchen, Germany) (2000).

Y. Kahana, Numerical Modelling of the Head Related Transfer Function. Ph.D. thesis, University of Southampton (2000).

B. Katz, Measuraments and Calculation of Individual Head-Related Transfer Function Using a Boundary Element Model Including the Measuraments and Effect of Skin and Hair Impedence. Ph.D. thesis, The Pennsylvania State University (1998).

B. Katz, Boundary element method calculation of individual head-related transfer function. I. Rigid model calculation. Journal of the Acoustical Society of America **110**(5) (2001a) 2440–2448.

B. Katz, Boundary element method calculation of individual head-related transfer function. II. Impedance effects and comparisons to real measurements. Journal of the Acoustical Society of America **110**(5) (2001b) 2449–2455.

K. Maki and S. Furukawa, Acoustical cues for sound localization by the

G. A. Spirou and E. D. Young,